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Publisher's version / Version de l'éditeur:

Journal of the Acoustical Society of America, 53, 6, pp. 1535-1543, 1973-06

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ACOUSTICAL PRIVACY IN THE LANDSCAPED OFFICE

BY

A. C. C. WARNOCK

REPRINTED FROM
THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA
VOL. 53, NO. 6, JUNE 1973
P. 1535 - 1543

RESEARCH PAPER NO. 570
OF THE
DIVISION OF BUILDING RESEARCH

OTTAWA

PRICE 25 CENTS

NRC 13435

LE SILENCE DANS UN BUREAU PAYSAGE

SOMMAIRE

On a mené une enquête quotidienne de la réaction d'un groupe de personnes travaillant dans un bureau paysagé contre différents sons servant à masquer les bruits. La réaction a été défavorable. Des entrevues ont indiqué que ces personnes n'ont aucun besoin pressant de silence, et que les bruits supplémentaires sont une intrusion. L'efficacité des sons de masquage est mesurée de manière objective et subjective. On fait des mesures de propagation sous un plafond plat afin de déterminer l'efficacité des écrans et des matériaux et déflecteurs de plafond. Les différences sont analysées en termes de l'index d'articulation, et on montre l'importance des faibles changements de l'index d'articulation en considérant l'aire d'intrusion d'un interlocuteur hypothétique.

CISTI/ICIST

3 1809 00211 3527

Acoustical privacy in the landscaped office

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(Received 27 November)

Two landscaped offices were used for field studies of the acoustical isolation value of masking noise, absorptive ceilings and partial-height screens. The occupants of one of the offices were recruited for a subjective study of the relative acceptability of various masking noises. The study showed that this group consistently preferred less noise — a conclusion that contradicts some previous experience. Interviews indicated that the acceptability of masking noise is closely linked to the occupants' activities and the resulting need for privacy. Propagation measurements were made under a flat lay-in ceiling configuration to determine the effectiveness of screens, ceiling materials and ceiling baffles. The ceiling baffles were not found to be a practical means of ensuring a low ceiling reflection coefficient. The results of the measurements are analyzed in terms of changes in articulation index. Consideration of the area disturbed by a hypothetical speaker emphasizes the importance of small relative changes in articulation index caused by small changes in physical parameters.

Subject Classification: 2.3.

INTRODUCTION

The landscaped office is becoming more and more prevalent and, as a result, the problems peculiar to it are being studied at some length. Especially in dispute is the precise value of certain elements to the landscaped office. Particular ceiling systems of varying degrees of complexity have their proponents and opponents. Ceiling baffles are praised or disparaged; screens also may be overrated or summarily dismissed. Electronic masking systems are regularly recommended but the noise spectrum used varies in character according to the dictates of the consultant or supplier.

The studies described here were carried out in two different offices with the intention of clarifying some of these issues. Both objective and subjective experiments were performed and each is dealt with separately. The subjective experiments were carried out in an office section measuring 180 ft × 60 ft where the staff was a mixture of professional, administrative, and clerical workers. One series of subjective experiments was designed to provide information on staff reaction to different masking spectra at different sound levels. A second series was meant to evaluate the masking effectiveness of the different sounds. Objective propagation studies were used to determine the importance of ceiling absorption and baffle and screen configuration.

I. USER REACTION TO MASKING NOISE

When an electronic masking system is used in an open office, it is usually advised that the staff be kept unaware of its existence. This avoids unnecessary problems with complaints from persons using the masking system as a focus for verbal sublimation of other unvoiced minor grievances.

However, in this case, some information on the staff's reactions to various levels and spectrum shapes was

desired and they were informed at the outset that a masking system would be in operation. They were told that it was believed that such a system would improve their working conditions and that their help was needed in ascertaining the best spectrum shape and optimum level of sound. Thus while the subjects were aware that their acoustic environment would vary they did not know just exactly how.

A. Experiment 1

Each day the office staff were presented with two different masking sounds, one in the morning and another in the afternoon. These sounds differed either in level or in spectrum shape but not both. The subjects were asked to mark a card giving their preference using a 5-point scale with the following categories: much prefer morning; slightly prefer morning; no preference; slightly prefer afternoon; and much prefer afternoon.

Figure 1 shows the spectra used in the experiment. Described generally, these diminished with frequency at 3, 5, and 7 dB/octave and were denoted 1, 2, and 3, respectively. The shape of spectrum 4 was adjusted by ear, without the use of a spectrum analyzer, until it was free of pronounced hiss, rumble, or other distinguishing feature. Three sound levels were used in the experiments: 51, 48, and 45 dBA. These are denoted A, B, and C. Thus B2 is spectrum 2 at a level of 48 dBA. (These levels do not include normal office noise, e.g., typewriters and conversational sounds.) During the course of the experiment the comparisons were repeated in reverse order to eliminate any possible time-of-day effects, but no such effects were found.

The results obtained from these comparisons were somewhat of a surprise to the experimenters. The office staff unequivocally rejected the masking noise system. When asked to choose between noises differing in level,

FIG. 1. Masking spectra used in obtaining user reaction. All are at a level of 48 dB, with the exception of the bottom ambient spectrum which is at a level of 45 dB_A. The curves are displaced from each other by 10 dB for clarity. These were all measured at a standard position in the middle of the office.

they clearly chose the quieter condition. When asked to choose between any two spectra, no marked preferences emerged. Even when asked to choose between spectra 1 and 2 there was no marked preference although spectrum 1 was deemed by the experimenters to have too much high-frequency content. Figure 2 summarizes most of the results obtained.

The induction heating/cooling units around the exterior walls of the office emitted a fairly loud hissing sound that was quite prominent in some areas and added to the general background noise level. For comparison the induction units were switched off for a day and a choice requested between 45-dB_A masking sound and the low background noise level of about 40 dB_A that resulted when the air diffusers were off. Even this very low background noise condition was preferred to the slight amount of masking noise.

B. Experiment 2

These results were quite unexpected and, in the hope of gaining some insight into the reasons for them, a longer experiment lasting two weeks was initiated. During the first week the spectrum marked B4 in Fig. 1 was broadcast at 48 dB_A. During the second week, the masking system was switched off. At the end of this experiment the staff were interviewed individually and asked for their reactions to the previous two weeks and about their privacy requirements. Quite a number of the staff had not noticed any difference between the two weeks but of those who had, the preference again was for the quieter condition.

From the interviews it was obvious that the staff in this particular office had no great desire for privacy and their work was of such a nature that intruding

speech sounds did not distract them. Thus, to this particular office staff, the masking noise was an unwarranted intrusion. It should be emphasized that this result is at variance with that obtained in other offices where the nature of the work demanded a higher degree of isolation. In those cases, the staff readily accepted an increase in background sound level to ensure a greater degree of privacy.

In one such experiment¹ employees with expressed need for privacy were allowed to adjust the level of masking noise to suit themselves. Initially the level was set at 50 dB_A but this was considered too high for comfort. After a few days the level settled on was 48 dB_A. This was considered unobtrusive but high enough to create a satisfactory privacy condition.

Other work² has shown that when the background level increases beyond about NC 40 (48 dB_A) persons talking will raise their voices to compensate for the increased noise. It would seem then that 48 dB_A is about the maximum masking level that can usefully be employed.

C. Experiment 3

One unfortunate feature of the above experiments was that the occupants of the space were made aware of the masking noise and questioned repeatedly about it. Thus, in this respect, the situation was artificial. It was considered worthwhile, therefore, to conduct one last experiment without forewarning the occupants. After three months of no artificial noise the masking system was again switched on and adjusted to about 1 dB_A above the natural background-noise level in the office. Each week the level was increased by about 1½ dB_A. When the level reached approximately 47 dB_A the sound was noticed and complaints were made about it.

FIG. 2. Summary of subjective reactions to masking noise. (a) Mean response when subjects chose between spectra at different levels. (b) Mean response when subjects were choosing between spectrum 2 and 3.

D. Conclusions

It was obvious from these experiments that there are office workers for whom aural privacy is not a prime consideration. Their work does not demand a high degree of concentration so they are not disturbed by sounds from neighboring work stations. For the group considered here low background noise levels were preferred, so no masking system should be used. The acoustical ceiling material was not particularly absorbent ($NRC=0.45$) but since the loss of privacy caused by ceiling reflections was not important, it was not necessary to install more efficient material.

Faced with designing an office for a group such as this, the designer could economize on acoustical frills and concentrate on more important factors affecting user satisfaction. If the structure of the organization is such that the office may be occupied at a later date by a staff requiring a higher degree of privacy, then economics may necessitate the initial installation of high-quality ceiling boards, absorptive treatment of vertical surfaces, and the wiring for a masking system, even if not immediately required.

II. SPEECH-INTELLIGIBILITY TESTS

A. Subjective Tests

The effectiveness of a given noise spectrum as a masking device can be estimated by making objective measurements and using standard articulation index calculations.³ It was considered worthwhile, however, to look into the possibility of a direct subjective measure of speech intelligibility.

The standard articulation index tests require the use of a trained test crew. In this case it was not possible to obtain a trained crew, and the services of about a dozen volunteers were used. They were given an audiometric examination and, provided their hearing was rated normal for their age, they were accepted. The resultant spread in aural acuity and listening skills was reflected in the test scores.

FIG. 3. Mean subjective score for different noise conditions normalized to score obtained under ambient conditions.

FIG. 4. Mean percentage score on Griffiths' rhyming test versus calculated articulation index for all test positions and noise conditions. The straight lines are linear regression lines.

The test chosen was one developed by Griffiths⁴ for another purpose. It was chosen for its ease of use and scoring and because no training is required for the test crew. The listeners are presented with a test form containing 250 words arranged in rhyming groups of five. The talker reads one of the five words and the listener is obliged to mark the one he believes he heard. The listener must make a guess if he is not sure what he heard and the chance score on the test, therefore, is 20%.

The test was administered in a central part of the office that was vacated during the lunch period. The talker monitored his voice level by observing the peak excursion on a sound-level meter set to the *A*-weighted scale with fast response and maintaining a peak excursion of 55 dBA. The estimated equivalent long-term rms of the speech is about 55 dB.

Thirteen listener positions were selected and after each test the listeners moved to new positions. Usually about eight to ten tests were administered under one masking sound condition during each lunch period. The mean score was then calculated for each position.

The results obtained were as expected, i.e., the louder the noise, the lower the score; the greater the noise in the critical bands around 2000 Hz, the lower the score. The mean subjective score in each position for all test conditions was normalized to the score obtained with no masking noise. These normalized scores were then averaged to produce Fig. 3, which shows the effectiveness of the different noise conditions in masking speech.

B. Objective Tests

It was considered of interest to compare the subjective scores obtained with objective predictions for each listener position and noise condition. To do this, propagation measurements and noise level measurements were made as follows:

(1) The speaker-listener propagation relation was determined by placing a loudspeaker at the talker position and measuring the drop in *A*-weighted level at each listener position. In each case the loudspeaker was

FIG. 5. Propagation in office with and without baffles on 5 ft centers. (a) 5-ft-high screen 3 ft from loudspeaker, (b) 5-ft-high screen 6 ft from loudspeaker.

turned directly to the listener position; a separate correction for talker orientation was made later.

(2) The background noise level in dBA in each position was measured for each test condition.

(3) From this information the articulation index was calculated in each case (assuming an ideal voice with a long-term rms level of 65 dB at 3 ft and assuming that the speaker was talking directly to each listener position). Azimuthal corrections were then made for the actual orientation of the talker. This resulted in a set of calculated articulation indices for each test condition and for each listener position.

The correlation between the calculated articulation index and the mean subjective test score can be seen in Fig. 4. The two lines are the linear regression lines. There is no *a priori* reason to expect a linear relationship but this analysis leads to a correlation coefficient of 0.82 which is quite satisfactory in view of the experimental conditions. It is necessary, however, to point out a discrepancy in the foregoing, i.e., that the ideal voice level assumed in the AI calculations was 65 dB whereas the real voice level was closer to 55 dB. This difference of 10 dB, if taken into account, forces a reduction in the calculated articulation index values of 0.33. This would mean that when the articulation index is zero, subjects can score 50% on the Griffiths' test.

This result seemed to warrant further investigation so a comparison between the standard intelligibility test⁶ and the Griffiths' test was made in the laboratory using a carefully selected and trained test crew. The results obtained exhibited the same behavior again. It

would seem that this feature then is a characteristic of the Griffiths' test.

To achieve acceptable privacy in an open office, (in the sense of freedom from intrusion), it is generally considered that the articulation index should be less than 0.15. In the range of articulation index from 0.35 down to zero, small changes in articulation index produce large changes in sentence intelligibility and any tests used to evaluate the articulation index in this region should either be very sensitive to small changes in articulation index or very accurate. The Griffiths' test is not sensitive enough in this region and unless used with a carefully selected crew, is not accurate enough. It must be concluded, therefore, that the Griffiths' test is not suitable for making quick, simple, reliable estimates of the articulation index in an open office.

In view of the difficulties associated with making subjective articulation index measurements, it would appear that objective measurements will remain the most common and most easily used method of obtaining articulation index estimations in the open office. Nothing in this work suggests that objective measurements are unsuitable.

III. PHYSICAL MEASUREMENTS

The measurements described here were performed in two different offices which had standard lay-in ceiling boards supported on T bars. The behavior of sound in offices was determined by broadcasting continuous pink noise from a loudspeaker and measuring the sound pressure level as a function of distance for different screen and baffle configurations and different ceiling materials. All the screens used were 5 ft wide. Figure 5 shows the *A*-weighted sound-pressure levels obtained in one office where baffles were added to the basic ceiling in a modified herringbone pattern which gave a separation of 5 ft. These baffles were 8 ft×1 ft and were made of glass fiber covered with porous cloth. The basic ceiling was mineral fiber tile which had a Noise Reduction Coefficient (NRC) of 0.45, as measured in a reverberation room on a No. 7 mounting. It can be seen that, in this case, the baffles did not decrease the signal measured behind the screen and therefore no improvement in privacy was obtained.

In the second office a study was made of two different ceiling boards used alone and with two different baffle configurations. The ceiling materials were A, fissured mineral-fiber board $\frac{5}{8}$ in. thick with an NRC of 0.55 and B, glass-fiber board $\frac{5}{8}$ in. thick faced with porous cloth, with an NRC of 0.85. The baffles were constructed from 4 ft×1 ft sheets of $\frac{1}{4}$ -in. plywood. These were covered on the side facing the loudspeaker with $\frac{5}{8}$ -in. glass fiber which was coated with a perforated vinyl. The baffles were suspended from the ceiling in parallel rows at right angles to the line of measurement. Baffle separations of 2 and 4 ft between rows were used.

The results of the propagation measurements made in the second office can be seen in Figs. 6 and 7 where they are displayed in dBA. In Fig. 6(a), for the more absorbent ceiling material, one can see that the addition of the baffles made very little difference to the *A*-weighted levels measured in the presence of the screen. In Fig. 6(b), for the harder material, the baffles do have an easily observed effect but only when placed on 2-ft centers. When the baffles are spaced thus, the less absorptive ceiling becomes about as effective as the more absorbent ceiling without baffles, in that the signal decreases more rapidly with distance. It can be concluded, therefore, that although baffles can be used to improve a reflective ceiling, the amount of absorbing material required is comparable to the ceiling itself. For new design it is economically sensible to install a more absorbent ceiling board.

Figure 7 has been included to facilitate comparison of the two basic materials without baffles. Two screen sizes are used and it is easy to see the advantage obtained by using a higher screen by comparing Figs. 7(a) and 7(b). It can also be seen that there is a systematic difference of about 3 dBA in sound-pressure level behind the screens when material B is substituted for material A. This would mean an improvement in articulation index of about 0.1 which is important in situations where the articulation index is in the neighborhood of 0.3.

The results in the second office were analyzed more thoroughly and Figs. 8(a) and 8(d) show octave band levels at a distance of 12 ft from the speaker for the two ceiling types and the different baffle configurations. The attenuation is measured relative to the levels 3 ft in front of the loudspeaker.

From such analyses it is possible to calculate the changes in articulation index that occur when changes are made in the ceiling baffle configuration, screen configuration, or basic ceiling material. Since the intrusiveness of speech or lack of speech privacy is the major

FIG. 6. Propagation with different ceiling materials and baffle arrangements for 4 ft 8 in. screen at 3 ft. (a) Material B, NRC=0.85. (b) Material A, NRC=0.65.

FIG. 7. Comparison of two ceiling materials without baffles for (a) 4 ft 8 in. screen at 3 ft. (b) 6 ft screen at 3 ft.

reason for making measurements such as these, it would seem more appropriate to express the results in terms of a quantity related to the intelligibility of speech rather than sound pressure levels. Table I shows the results obtained when relative changes in articulation index are calculated for a distance of 12 ft from the loudspeaker. The reference condition chosen is that existing under the less absorbent ceiling with no baffles and no intervening screen at a distance of 12 ft.

Tables such as this can easily be prepared for any relevant distance from the loudspeaker. They provide a quick comparison of the effects that the different combinations have on the intelligibility of speech. For a given screen configuration, the effects of changing the ceiling material or baffle configuration can be obtained by reading along a row. For a fixed ceiling condition, the benefits obtained by altering screen size and distance from the source are found by reading down a column.

The conclusions to be drawn from Table I are in essence the same as those already stated. The addition of the baffles on 2-ft centers can improve the acoustically hard ceiling until it is as good as the more absorbent ceiling. However, as already noted, this is not usually an economically sound solution. The results obtained with baffles added to the more absorbent ceiling seem slightly at odds with the dBA results but this might be attributed to the fact that the glass-fiber ceiling board is relatively transparent to sound and there may be some anomalies due to plenum effects. In any event, the baffles do have some effects but would again appear to be an unattractive solution.

In view of the improvement obtained by utilizing a more absorbent ceiling material, one might reasonably assume that the signal received behind the screen could be reduced still further by using a material that is as absorbent as possible. This obviates the need for baffle construction and installation. Ceiling boards approaching NRC values of 1.0 are readily available but, un-

TABLE I. Calculated decrease of articulation index with respect to a reference condition at 12 ft from the loudspeaker under material A with no intervening screen and no baffles.

Screen conditions	Material A			Material B		
	No baffles	Baffles 4 ft o.c.	Baffles 2 ft o.c.	No baffles	Baffles 4 ft o.c.	Baffles 2 ft o.c.
No screen	0.0	-0.06	0.01	0.02	0.02	0.02
4 ft 8 in. screen at 3 ft	0.16	0.17	0.28	0.25	0.32	0.29
6 ft screen at 6 ft	0.20	0.23	0.33	0.32	0.39	0.41
6 ft screen at 3 ft	0.28	0.32	0.41	0.38	0.40	0.47

fortunately, circumstances prevented their being tested under these conditions. In the light of other research,² one must assume that a more absorbent ceiling would perform at least as well as the best configuration tested here.

As the experimental data point to the interaction of screen and ceiling as the most important privacy-determining factor, it seems convenient at this point to consider the function of a screen in the open office. Sound at the important speech frequencies can reach the other side of a screen in four ways: by direct transmission through the screen; by diffraction around the screen; by reflection from vertical flanking surfaces; and, by reflection from the ceiling.

The direct transmission can easily be reduced to a negligible level by the appropriate choice of construction materials. In the absence of any flanking reflections, the insertion loss of a screen of a given size in a given configuration is determined by diffraction and can be estimated from the work of Maekawa.⁶ In a large open office, flanking due to reflection from vertical surfaces may be a problem around the perimeter and in the vicinity of columns, large filing cabinets, or other pieces of furniture. However, any such potential reflectors, especially perimeter walls and columns, are generally treated with absorbent materials. The dominant reflecting surface that affects every work station is the ceiling.

It is a straightforward task to calculate the magnitude of a signal reflected from the ceiling to a neigh-

boring work space if the reflection coefficient for the particular angle of incidence is known. To illustrate the importance of the ceiling-reflection properties Fig. 9 has been produced and shows the articulation index calculated for two screen sizes as a function of ceiling-reflection coefficient. For the purposes of this figure, an ideal voice of 65-dB long-term rms was assumed with the octave band levels shown in Table II. This table also shows the assumed noise spectrum which has a level of 48 dBA. The talker and listener were assumed to be at a height of 4 ft under a 9-ft-high ceiling and separated by a distance of 12 ft. The diffracted signals shown in Table II were calculated according to Maekawa's data for a semi-infinite screen, while the reflected signal was obtained assuming the same reflection coefficient in each band. Although this is an idealized calculation such considerations lead to the same conclusion as does the empirical data, namely that the ceiling is the single most important acoustical surface in the open plan office in that it determines the performance of the screens.

The ceilings investigated here were standard flat systems modified by adding baffles. Coffered ceilings and open systems with absorbent baffles suspended below exposed service ducts have been proposed and used. At this time one can only guess at the performance of these systems. Obviously a simple measurement of absorption will not suffice and the problem of rating such ceilings requires research and discussion.

FIG. 8. Octave band attenuation with respect to levels measured at 3 ft for speaker-microphone separation of 12 ft. (a) Material A, 6 ft screen at 3 ft. (b) Material B, 6 ft screen at 3 ft. (c) Material A, 4 ft 8 in. screen at 3 ft. (d) Material B, 6 ft 8 in. screen at 3 ft.

FIG. 9. Articulation index calculated behind screens 5 ft and 6 ft high for varying ceiling reflection. Talker-listener separation is 12 ft.

IV. PULSE MEASUREMENTS

The propagation experiments described so far used continuous pink noise as a signal. The received signal level therefore included diffracted sound, and ceiling and other reflections. Steps were taken to eliminate most of the unwanted reflections but these were not entirely successful. In an attempt to separate these components, some propagation measurements were made in the second office using pulses of sound instead of continuous random noise. The pulse received at a movable microphone was displayed on an oscilloscope and compared with a reference pulse, monitored 6 in. in front of the loudspeaker. It was possible to identify the combined direct and diffracted pulses that arrived first and reasonably accurate results were obtained for these.

Figure 10 shows the direct pulse level as a function of distance for two frequencies, 1000 and 2000 Hz, and for three screen conditions. From this one can estimate the ultimate attenuation that is possible with the screen at these two frequencies without reflections. The insertion loss obtained for the 6-ft-high screen agrees quite well with predictions from Maekawa's theory. The agreement is not as good for the smaller screen but this is probably due to the relatively large size of the source.

Comparing the values of attenuation at the 12 ft distance in Fig. 10 with those in Fig. 8, one can see the differences due to flanking reflections. The reflections were easily seen in the oscilloscope photographs but the complexity of the traces precluded complete identification of the surfaces causing the reflections.

To some degree it was possible to identify the pulse from the ceiling. However, the pulse was generally distorted and mixed with other reflections from unidentified surfaces and the accuracy obtained for the ceiling reflection measurements was too low to allow reliable conclusions to be drawn.

V. AREA OF DISTURBANCE AROUND A TALKER

The changes in articulation index or signal level found to be important in experiments such as these

TABLE II. Octave-band levels (in dB) used to calculate AI behind screen under different ceilings. (The results of the calculations are shown in Fig. 13.)

	Octave-band center frequency				
	250	500	1000	2000	4000
Peak voice signal at 12 ft in absence of screens	60	61	56	50	46
Noise spectrum [48 dBA]	48	47	43	37	31
Diffracted voice signal for 6 ft screen at 6 ft	50	49	43	33	26
Diffracted voice signal for 5 ft screen at 6 ft	52	52	46	38	32

FIG. 10. Direct pulse measurements in second office for (a) 1000 Hz. (b) 2000 Hz.

often appear quite small to lay observers who are only concerned with the most economical method of obtaining user satisfaction. It has been found effective to translate these signals and AI changes into the area or range of disturbance around an individual occupant. This permits a strictly economic approach to the assessment of the influence of various acoustical parameters.

Over a fairly wide range in AI one can write without serious error:

$$AI = [\text{Speech long-term rms (dB)} + 12 - \text{Noise [dBA]} + k] / 30.$$

Constant k takes into account the varying effectiveness of the masking noises due to spectral differences. An examination of some typical spectra showed that this constant is usually in the range $-2 < k < +2$. The expression above is in error at the extremes of the range of AI and would not hold for spectra that were very different from the ideal speech contour or the typical fairly smooth masking spectrum which is commonly used. For the purposes of this discussion, however, it is quite adequate.

The voice level at any required distance can be estimated by assuming a level of 65 dB at 3 ft from the talker and a reduction of 5 dB for each doubling of distance. (This value may be limited by reflections from the floor.) The lack of rigor in the foregoing and in the ensuing approach is considered acceptable in view of the resulting heuristic simplicity. With these two assumptions and an assumed noise level of 48 dBA, which would appear to be optimum, one only has to know the value of k for the particular spectrum in use to be able to calculate the AI at any distance in the absence of any intervening screens. Figure 11 gives an example of idealized plots of AI versus distance for the different conditions listed in Table III, which also lists some of the information gleaned from the figure. Using such a diagram and the corrections from Table I, it is easy to illustrate how a small change in AI caused by improving the masking spectrum or by altering the screen condi-

TABLE III. Illustration of effects of screen and ceiling changes on privacy conditions and area of disturbance cardioid.

Screen conditions	Spectrum k	Ceiling NRC	Relative change in AI due to screen (from Table I)	AI and privacy rating at 12 ft in front of speaker	Frontal distance for AI=0.15, ft	Area of disturbance cardioid ft ²
No screen	0	0.55	0	0.63—Nil	...	...
4 ft 8 in. screen at 3 ft	0	0.55	-0.16	0.47—very poor	44	2600
4 ft 8 in. screen at 3 ft	0	0.85	-0.25	0.38—very poor	30	1100
4 ft 8 in. screen at 3 ft	-2	0.85	-0.25	0.31—marginal	23	640
6 ft screen at 3 ft	-2	0.85	-0.38	0.18—marginal	14	210

tions can make substantial changes in the distance one has to retreat to attain acceptable privacy.

A. The Disturbance Cardioid

To show how changes in articulation index can influence the useful area in an office, one must first consider the effects of talker orientation on AI. To this one makes the simplifying assumption that a talker rotation of 30° relative to the listener will cause a decrease in AI of 0.05. With this assumption, a contour can be drawn around an individual which is the locus of AI=0.15. Assuming that the screen conditions are constant for all azimuthal angles, the contour is heart shaped and is called, for convenience, the "disturbance cardioid." Obviously, such a derivation is artificial since office staff are not usually totally enclosed by screens. Nevertheless, a consideration of the area of these cardioids dramatically underlines the effect of small changes in AI.

Figure 12 shows four cardioids corresponding to the four conditions b, c, d, and e in Fig. 11 and Table III. The areas of these cardioids are marked on the figure and are also listed in the Table II. The area changes are clearly quite large. However, Fig. 13, which is a plot of cardioid area versus the value of the articulation index at 12 ft from the talker, shows that when one is almost in the acceptable privacy zone, a change in AI

of 0.05 means a cardioid area change of about 75 ft². In the same zone, this change of AI causes a change of 3 ft in the distance one must be from the talker to obtain acceptable privacy.

Although this treatment of the disturbance caused by the speech of an individual is to an extent idealized, in practice the problem facing the designer is the allocation of floor area in a large office. This is undeniably a two-dimensional problem and it would seem to be necessary to interpret the acoustics of the open office in a two-dimensional fashion. In considering the interaction between two adjacent workspaces, it is of course easier to make point-to-point calculations. However, when comparing the efficacy of two systems, what is of interest is the area that must be allocated to each occupant in order to have an acceptable design. In this case a rating based on area, such as the disturbance cardioid, is useful. Disturbance cardioids could also be used as a design aid in allotting office space. This would require some information on the acoustical performance of the screens and ceiling assembly to be used.

With an interpretation such as the one outlined above it becomes much easier to demonstrate the importance of making small improvements to the articulation index.

VI. CONCLUSIONS

There never was any doubt that a masking noise system would lower the signal-to-noise ratio in an open

FIG. 11. Variation of articulation index with distance from the speaker (a) No intervening screen; 48 dBA noise with $k=0$. (b) 4 ft 8 in. screen 3 ft from talker; 48 dBA noise with $k=0$, ceiling material A. (c) 4 ft 8 in. screen 3 ft from talker; 48 dBA noise with $k=0$, ceiling material B. (d) 4 ft 8 in. screen 3 ft from talker; 48 dBA noise with $k=-2$, ceiling material B. (e) 6 ft screen at 3 ft from talker; 48 dBA noise with $k=-2$, ceiling material B.

FIG. 12. Disturbance cardioids corresponding to the four conditions b, c, d, and e in Table III. The numbers are the areas in square feet.

FIG. 13. Area of disturbance cardioids versus articulation index at 12 ft in front of talker.

office and hence lower the intelligibility of intruding speech. It was widely held, however, that aural privacy was extremely important in open offices. Our findings would indicate that there are cases where this is not so. Conversely, experience with other installations has clearly demonstrated that lack of privacy can cause a great deal of discontent.

The point that should be borne firmly in mind then is that, where the work function does not demand a high degree of privacy, the design process can proceed along much less acoustically rigid and more economical lines, although some treatment is still necessary to provide comfortable and pleasant surroundings. This is of course inconsistent with the major virtue of the open office which is the quick rearrangement of people and activities in the space, and the office could not then be successfully used at a later date by a staff with greater need for privacy.

If future use includes a possible increase in privacy needs, then economics would dictate a good initial acoustic treatment. While the office is occupied by a staff less concerned with privacy, it is probably best to keep the masking sound off or at a very low level. Otherwise the use of the system, even unannounced, may lead to some user dissatisfaction. Where a masking system is used to attain privacy it is best not to announce its presence. Little good will come of operating it at a level greater than 48 dBA.

Absorbent ceiling baffles can be used to improve a relatively reflective ceiling but only when they are mounted closely together. This is not an economical

design approach for reducing ceiling reflection. The most simple solution to the problem of reflection from a flat ceiling seems to be the use of a highly absorbent ceiling material which corroborates a conclusion reached previously.²

The propagation of sound from one side of a screen to a point on the other side is the core problem in obtaining privacy in the open office. One has to consider direct, diffracted, and reflected sound waves. A comparison of the short pulsed sound study with the continuous sound results seems to indicate that the major component is usually the reflected sound. The work of Maekawa confirms this and predicts that, in the absence of ceiling or other reflections, the screens will perform well enough to provide privacy at typical distances. The best ceiling then is obviously one that gives no reflection at all, but an adequate ceiling need only allow the screen to perform as well as is necessary to achieve privacy at typical separations.

In addition to the flat sound-absorbing ceilings discussed here, other systems such as coffered ceilings have been used. To complicate matters further sound absorption must generally be integrated with lighting and ventilation requirements as well. There is, therefore, need to develop acoustical criteria and test methods that can be applied to all such systems, preferably both in the laboratory and in the field.

ACKNOWLEDGMENT

This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the director of the Division.

¹L. W. Hegvold, "Experimental Masking Noise Installation in an Open Planned Office," Nat. Res. Council of Canada, Div. of Building Research, Tech. Note No. 563, 1971.

²R. N. Hamme and D. N. Huggins, "The Problem of Acoustical Specifications for Office Landscape Ceilings," J. Acoust. Soc. Am. **52**, 120 (1972).

³"American National Standard Methods for the Calculation of the Articulation Test," ANSI S3.5, 1969.

⁴J. D. Griffiths, "Rhyming Minimal Contrasts: A Simplified Diagnostic Articulation Test," J. Acoust. Soc. Am. **42**, 236 (1967).

⁵"American Standard Method for Measurement of Monosyllabic Word Intelligibility," S3.2, 1960.

⁶Z. Maekawa, "Noise Reductions by Screens," Appl. Acoust. **1**, 157 (1968).

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